Multi-core Intel® Processor Architecture: Software Development Tools

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Agenda

- Parallel Processing
- Thread Level Parallelism
  - Programming
  - Analysis
  - Optimization

Intel® Architecture

Instruction Level Parallelism

- Out-of-order instruction pipeline
- Multiple execution units

Data Level Parallelism

- MMX™
- Streaming SIMD Extensions (SSE)
- Streaming SIMD Extensions 2 (SSE2)
- Streaming SIMD Extensions 3 (SSE3)

Thread Level Parallelism

- Hyper-Threading Technology (HT Technology)
- Multi-core Intel processor architecture

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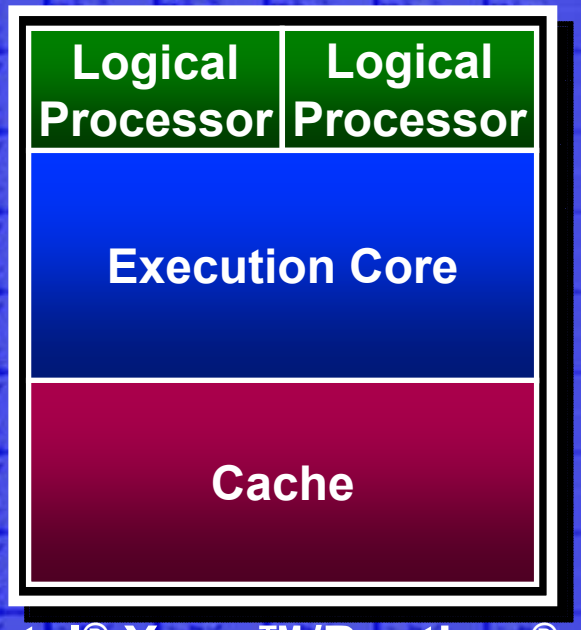
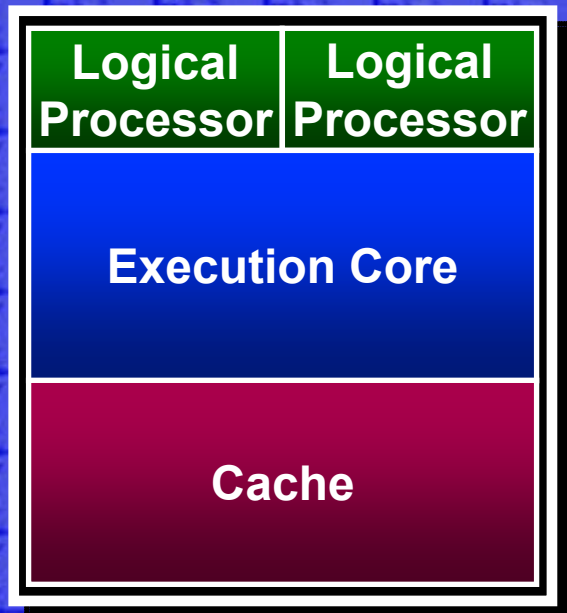
Hyper-Threading Technology (HT Technology) & Multi-core Intel processor architecture



Intel® Xeon™/Pentium® 4 processor supporting Hyper-Threading Technology

Hyper-Threading Technology (HT Technology) & Multi-core Intel processor architecture



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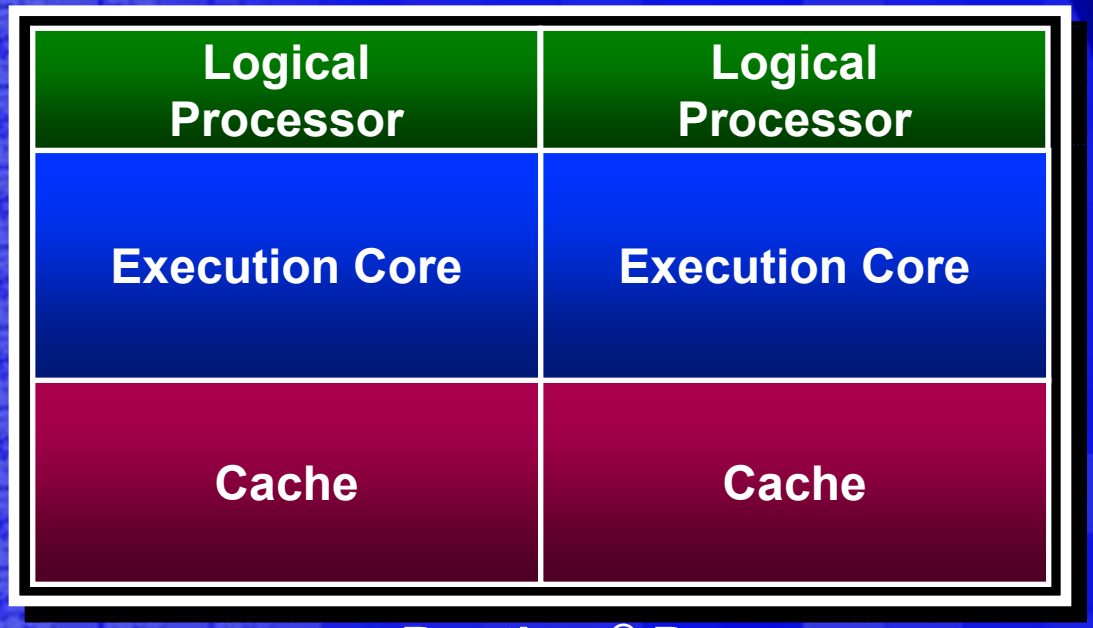
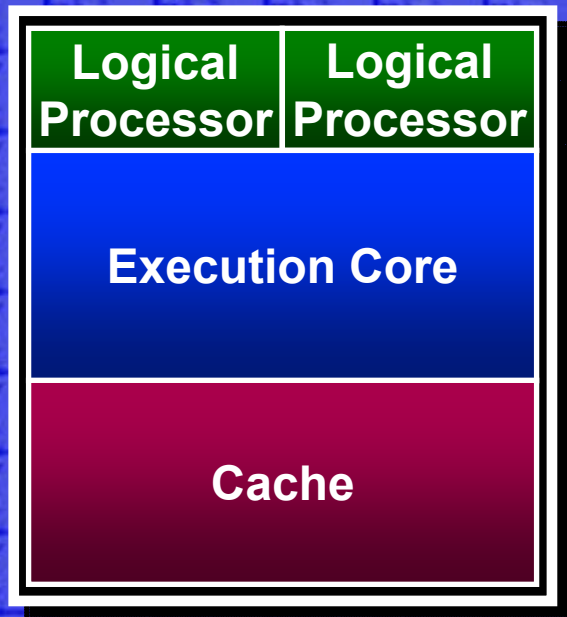


Pentium® D

Hyper-Threading Technology (HT Technology) & Multi-core Intel processor architecture



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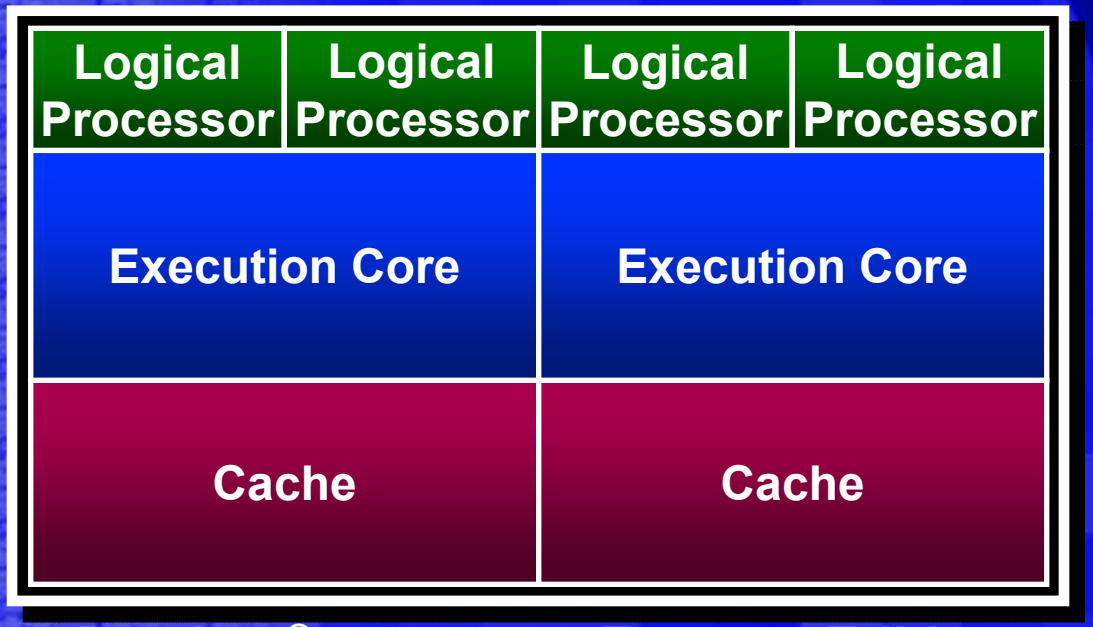
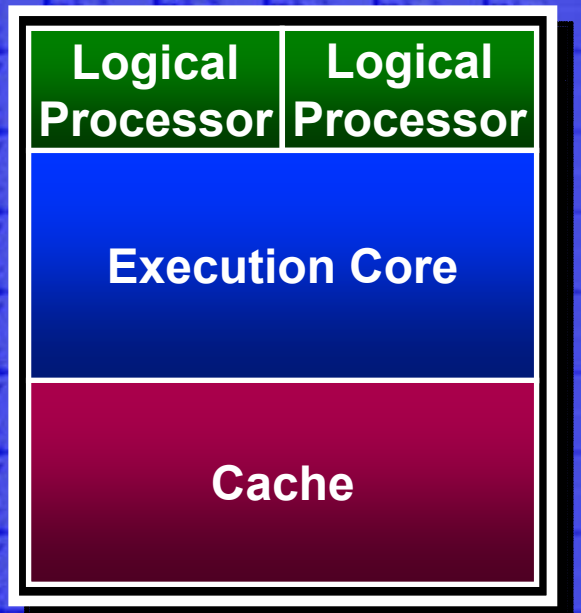
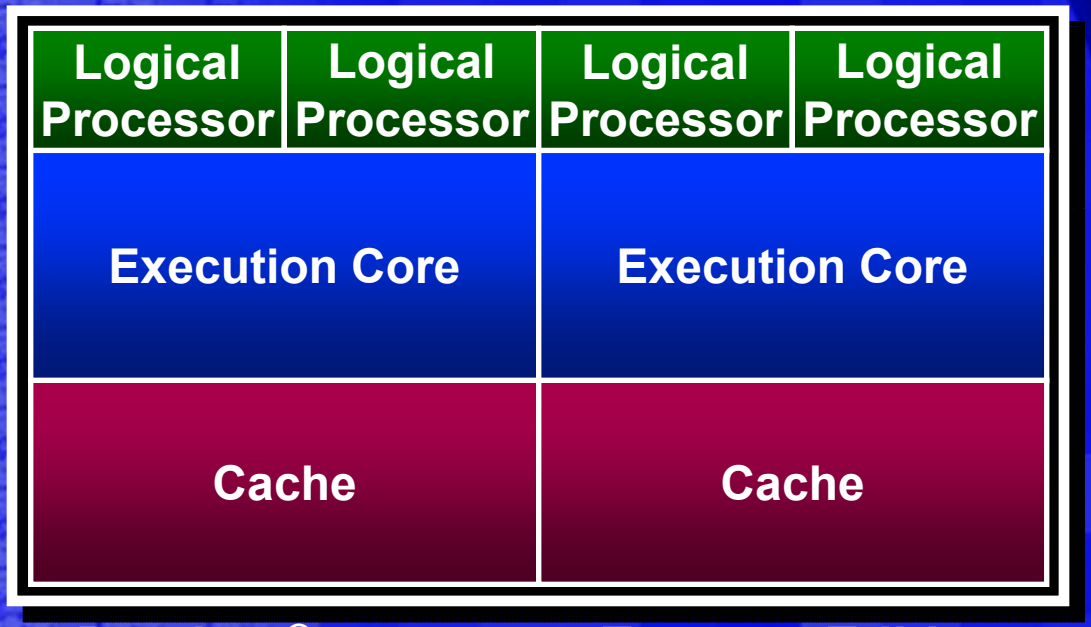


Pentium® processor Extreme Edition

Hyper-Threading Technology (HT Technology) & Multi-core Intel processor architecture



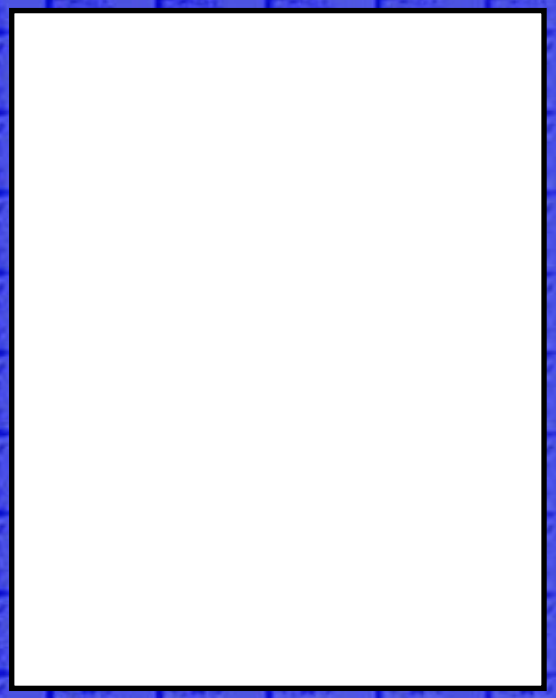
Intel® Xeon™/Pentium® 4 processor supporting Hyper-Threading Technology



Pentium® processor Extreme Edition

Multiple execution cores ramping across Intel platforms

Programming Model



- Modern operating systems load programs as processes
- A process starts executing at its entry point as a thread
- Threads can create other threads within the process
- All threads within a process share code & data segments
- Threads have two scheduler states (active, inactive)
- OS schedules active threads to execute on logical processors

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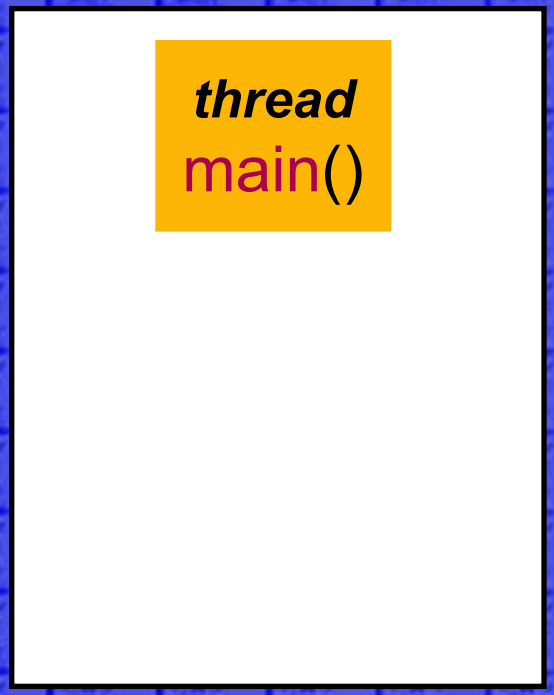

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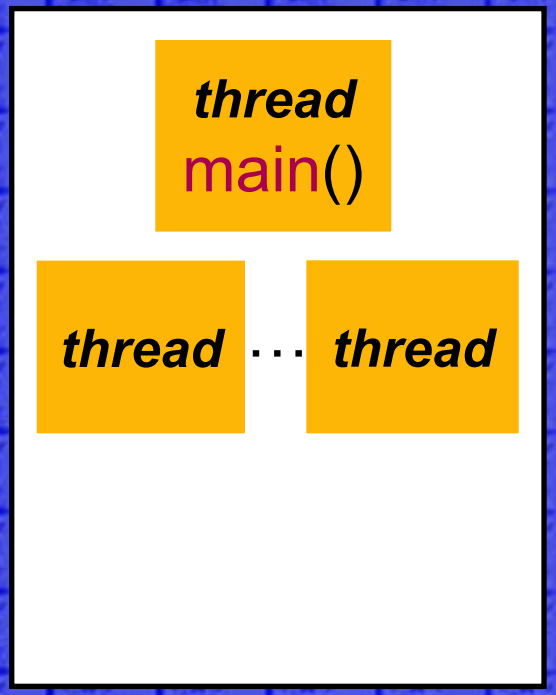

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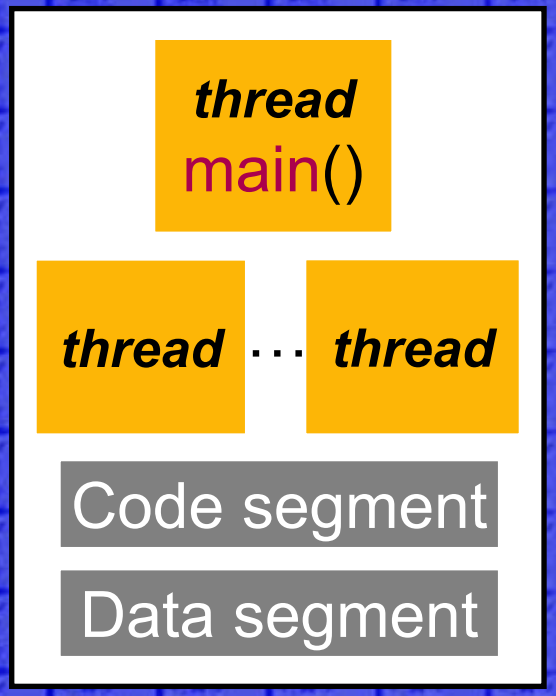

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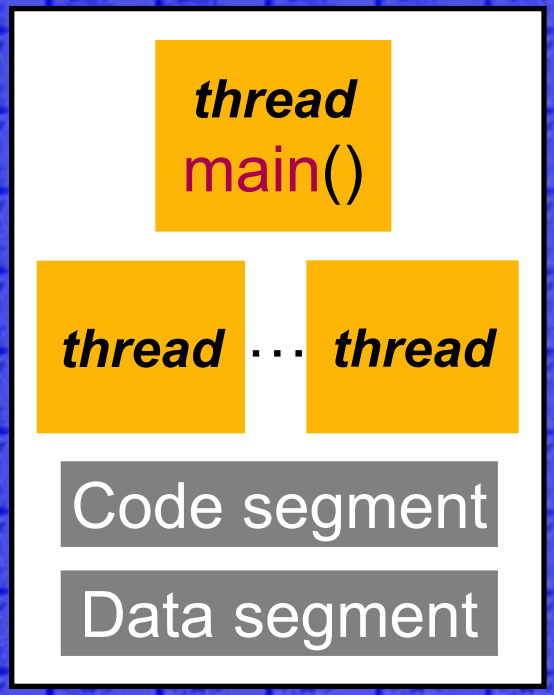

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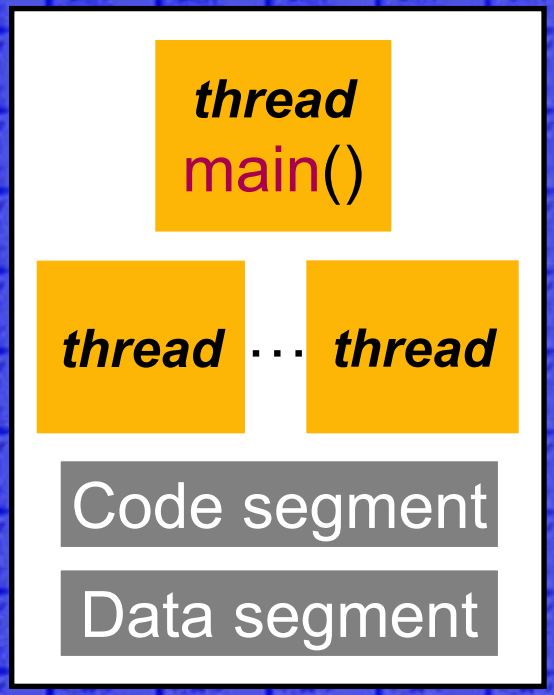

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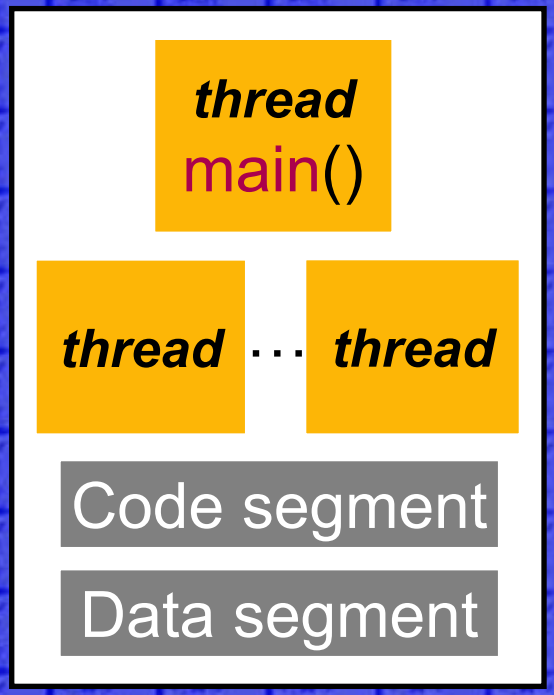

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Decompose algorithms across parallel compute threads

Example: Prime Number Generation

```
#include <stdio.h>
const long N = 18;
long primes[N], number_of_primes = 0;
main()
{
  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case
  for (long number = 3; number <= N; number += 2 )
  {
    long factor = 3;
    while ( number % factor ) factor += 2;
    if ( factor == number )
      primes[ number_of_primes++ ] = number;
  }
  printf( "Found %d primes\n", number_of_primes );
}
```

Example: Prime Number Generation

2

3	3
5	3,5
7	3,5,7
9	3
11	3,5,7,9,11
13	3,5,7,9,11,13
15	3
17	3,5,7,9,11,13,15,17

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    while ( number % factor ) factor += 2;
    if ( factor == number )
      primes[ number_of_primes++ ] = number;
  }
  printf( "Found %d primes\n", number_of_primes );
}
```

```
Determining primes from 1-18
Found 7 primes
Press any key to continue_
```

Example: Prime Number Generation

```
#include <stdio.h>
const long N = 1000;
long primes[N], number_of_primes = 0;
main()
{
  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case

  for ( long number = 3; number <= N; number += 2 )
  {
    long factor = 3;
    while ( number % factor ) factor += 2;
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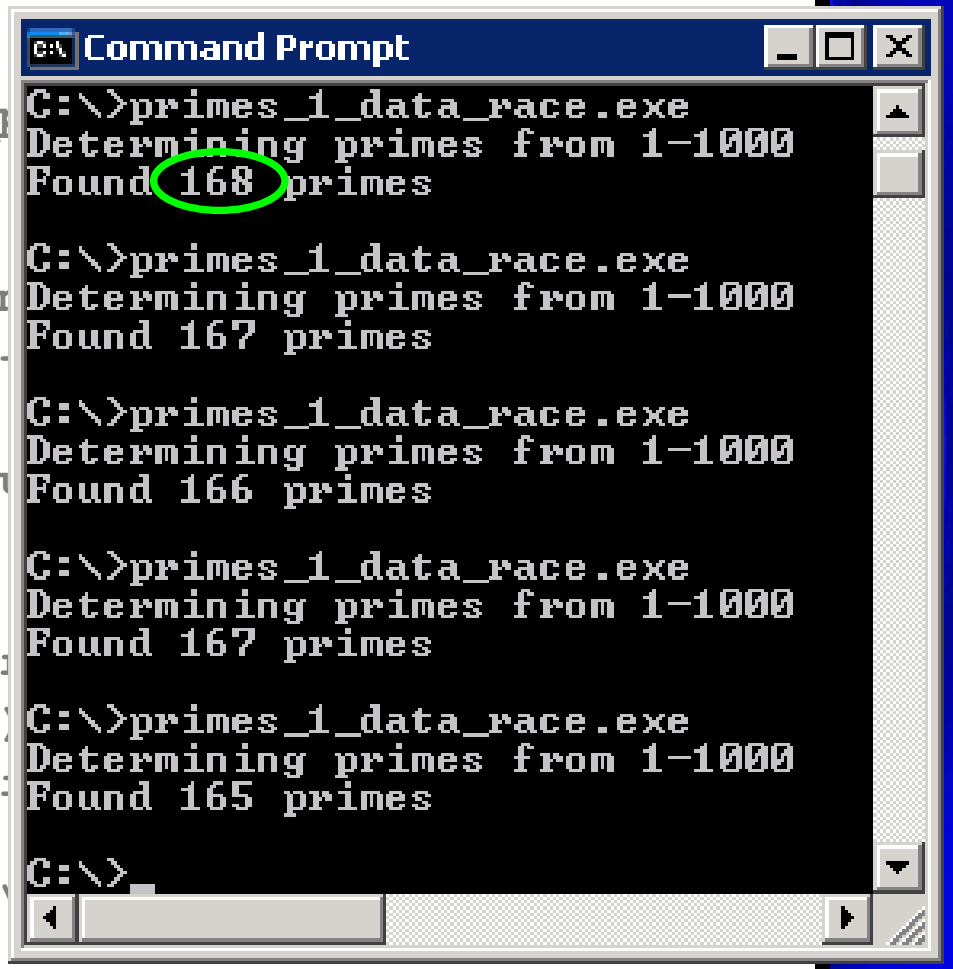

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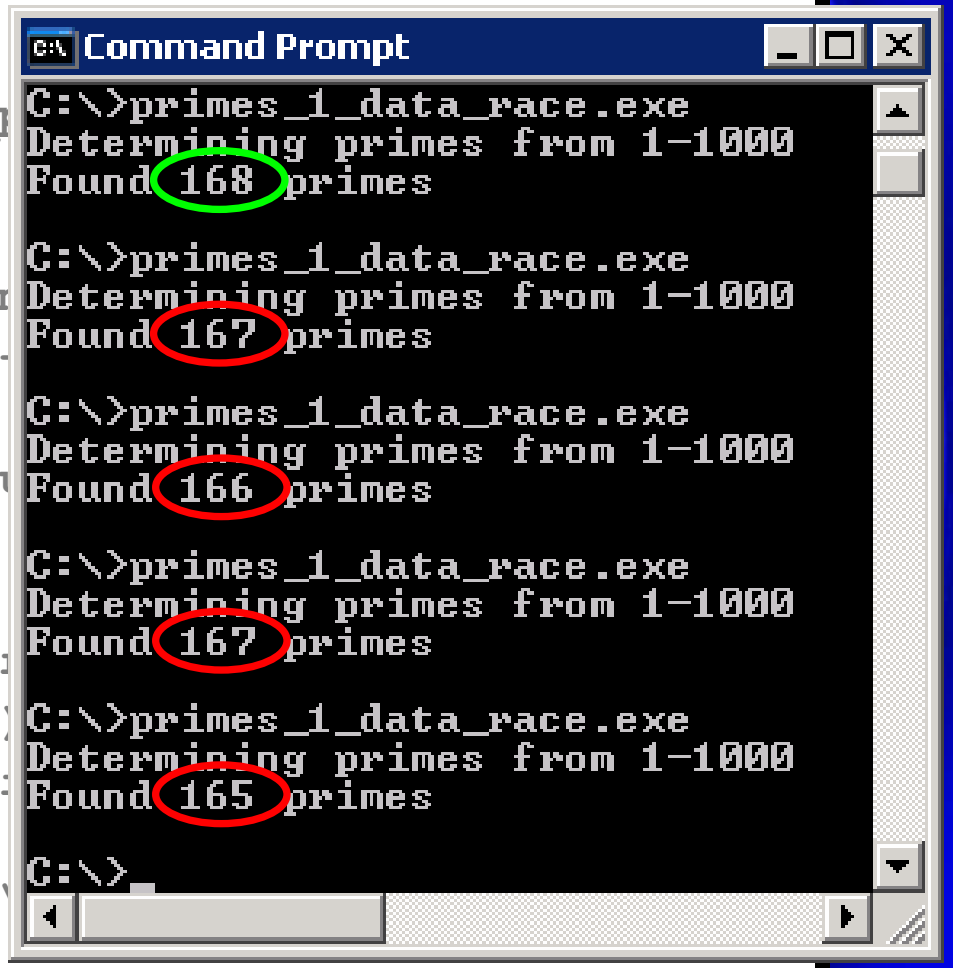

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  }
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Example: Prime Number Generation

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#include <stdio.h>
const long N = 100000;
long primes[N], number_of_primes = 0;
main()
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  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case
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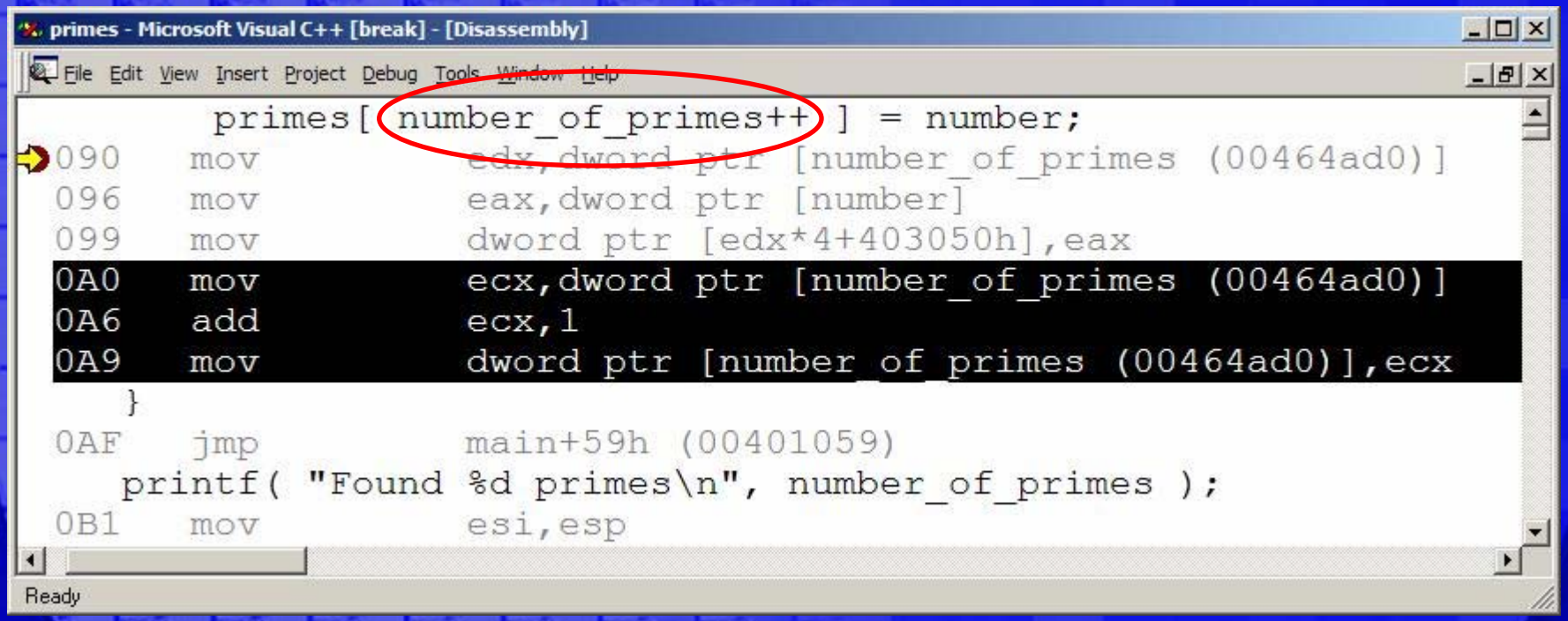
Pre-emptive context switching and shared memory conflicts (Data Races)



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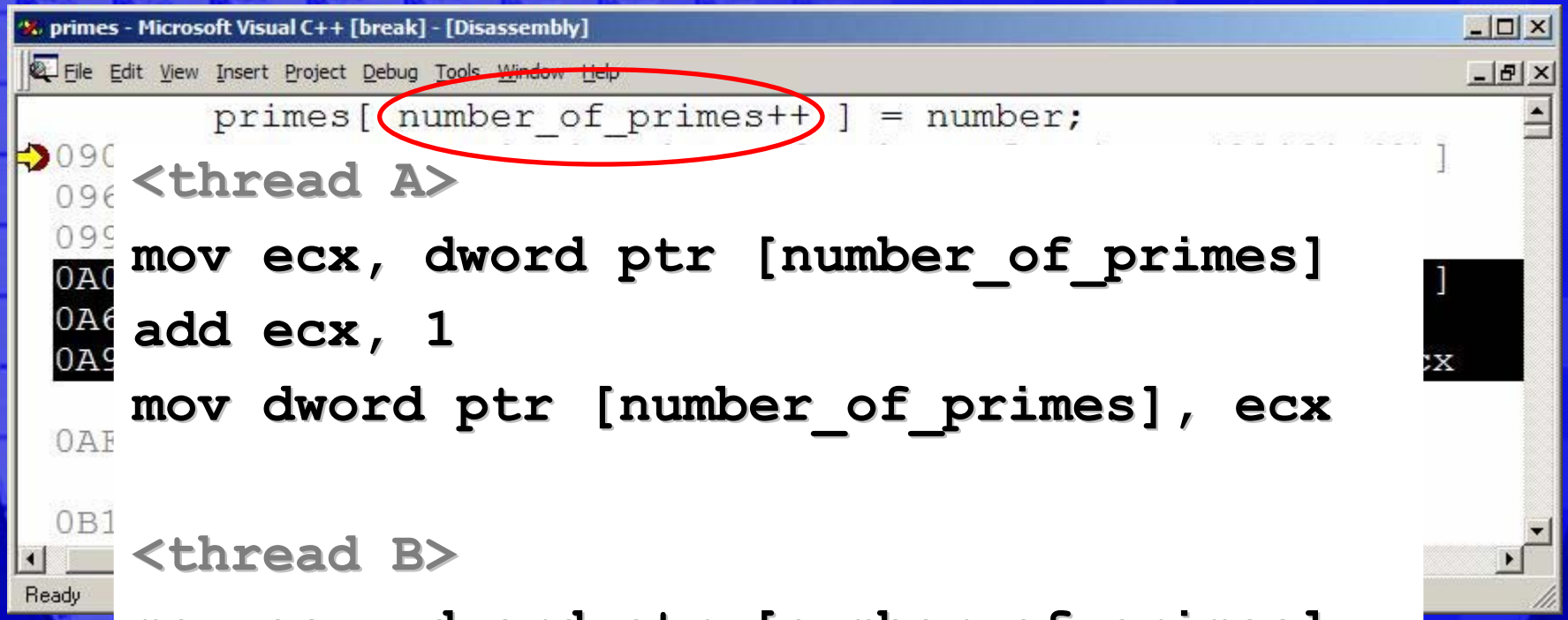

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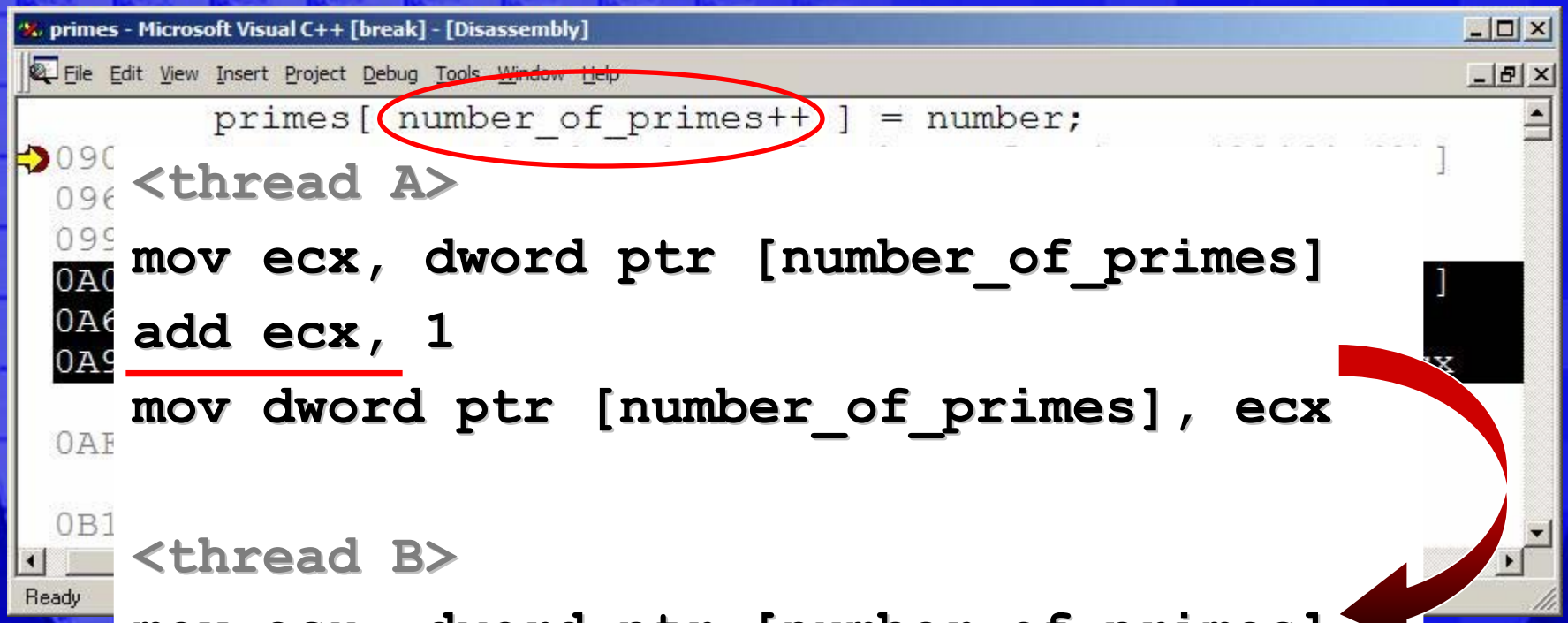

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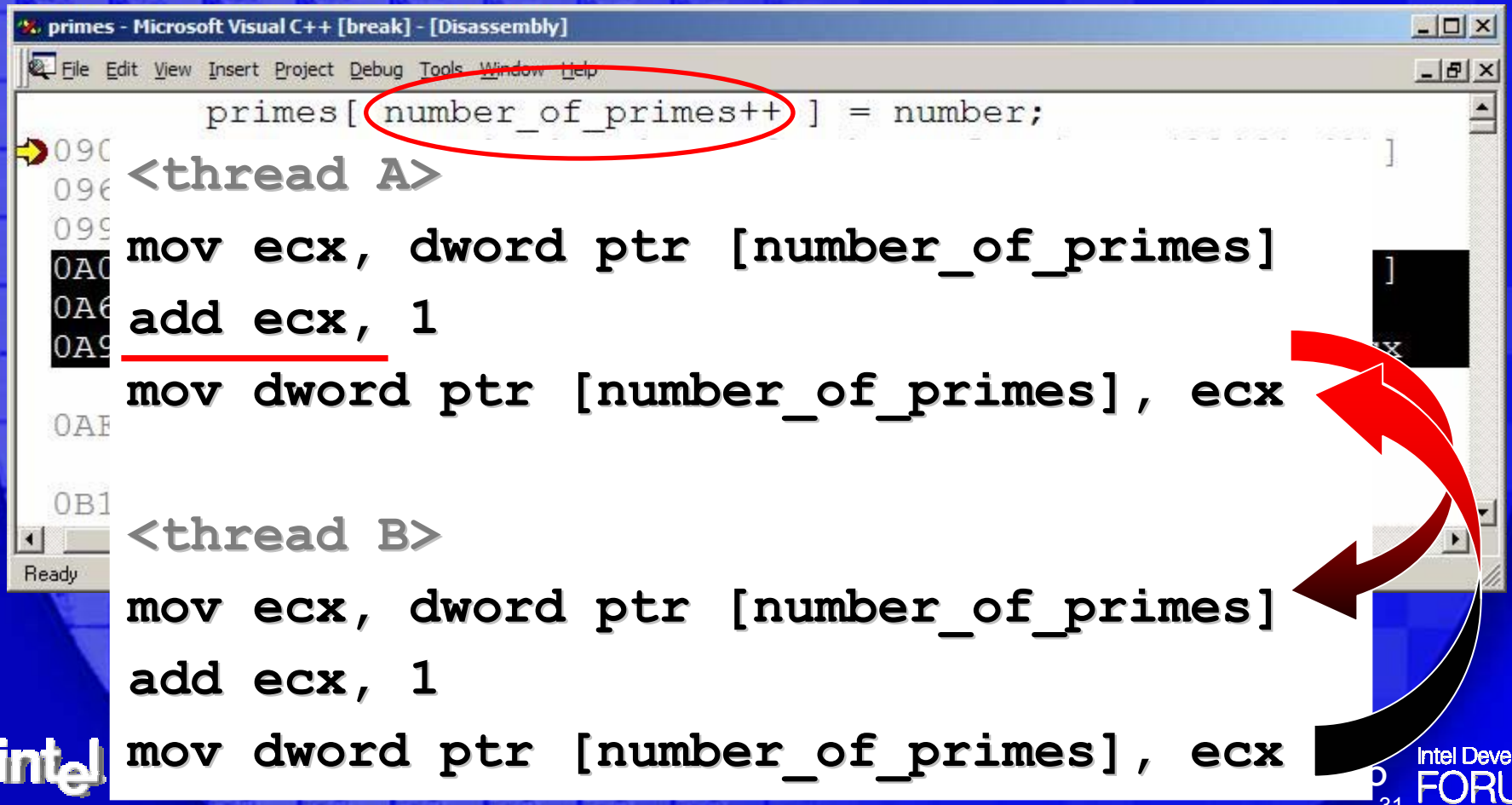

Data Race

```
int s;
threadA() {
  …
  s = 1;
  int A = s+1;
  …
threadB() {
  …
  s = 2;
  int B = s+1;
  …
```

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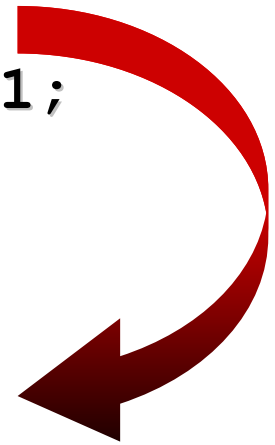

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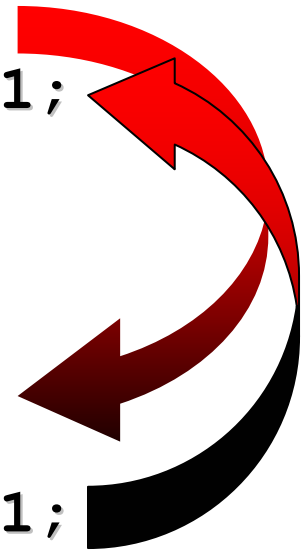

Synchronized Resource Sharing

```
int s; mutex m;
threadA() {
  lock(&m);
  s = 1;
  int A = s+1;
  unlock(&m);
threadB() {
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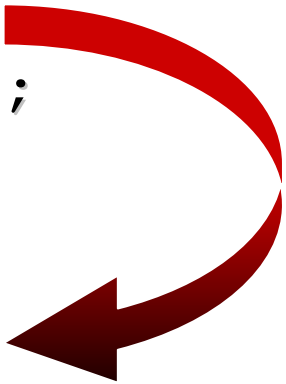

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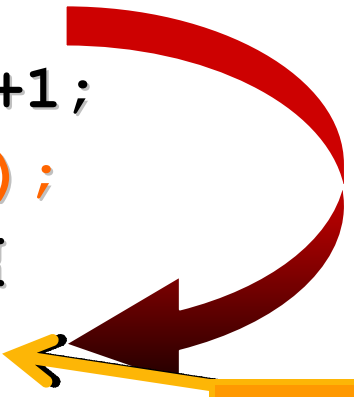

Does not return until acquired

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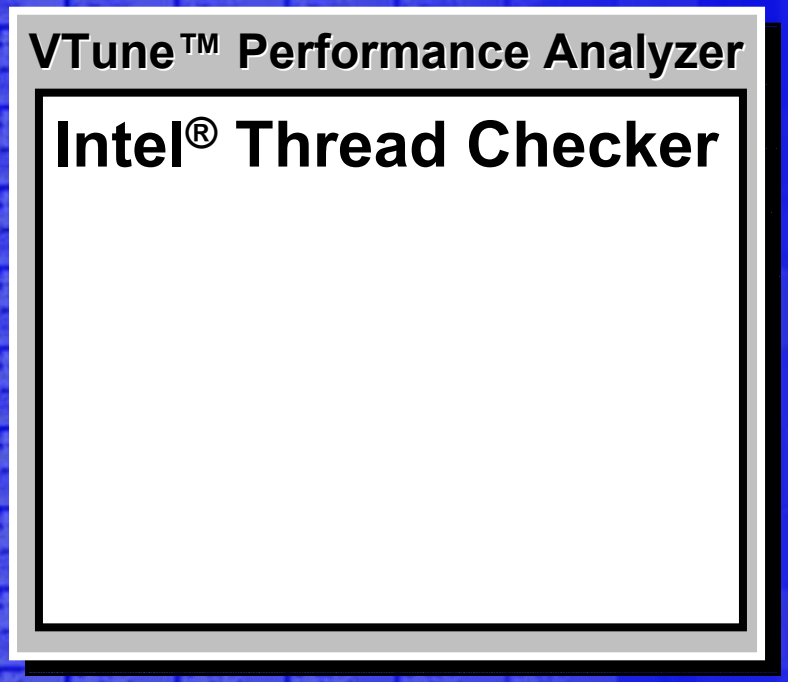
Intel® Threading Tools

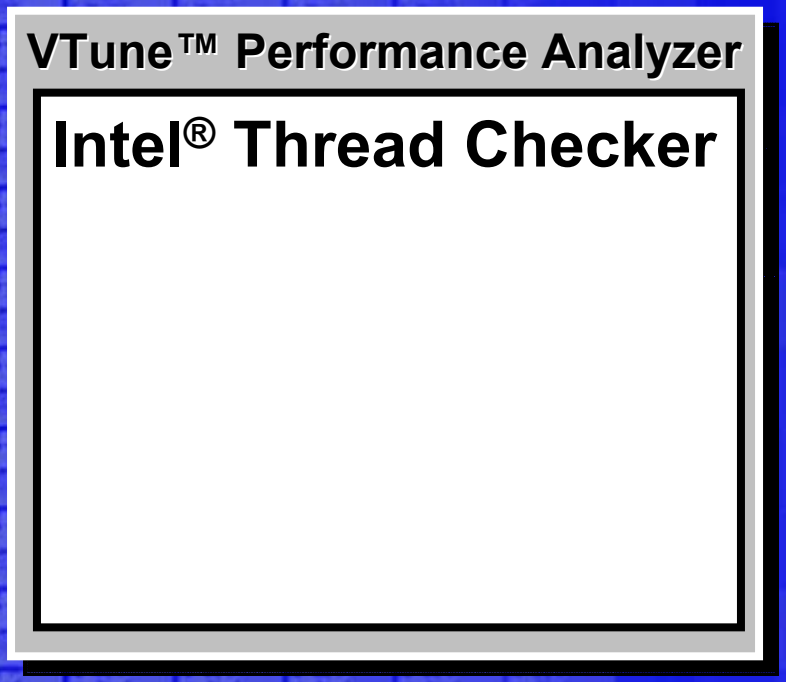
Intel® Thread Checker

- Pinpoint notorious threading bugs like data races, stalls and deadlocks

Intel® Thread Checker



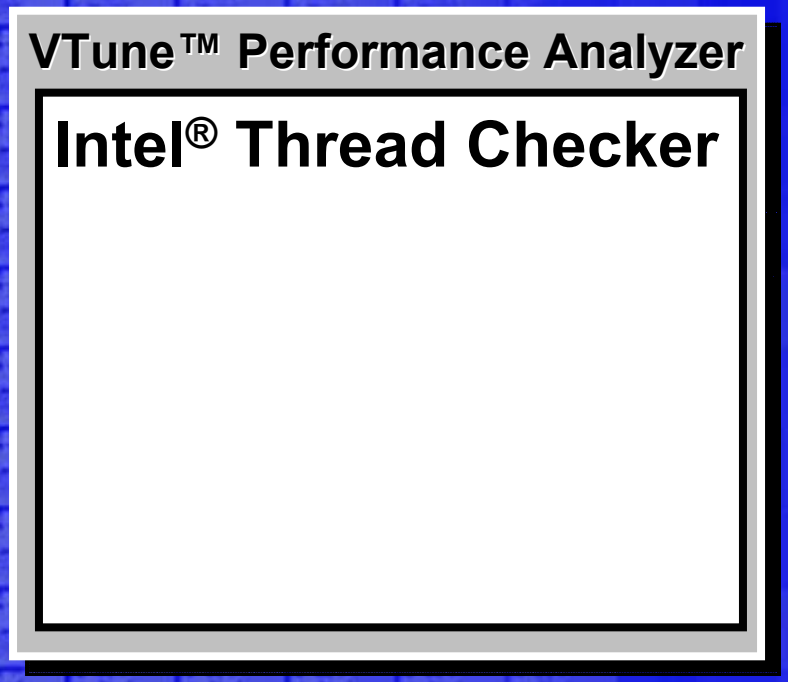
Intel® Thread Checker



Primes.exe*

*Compilation options: /Zi /O0
*Link options: /debug /fixed:no

Intel® Thread Checker



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*Compilation options: /Zi /O0
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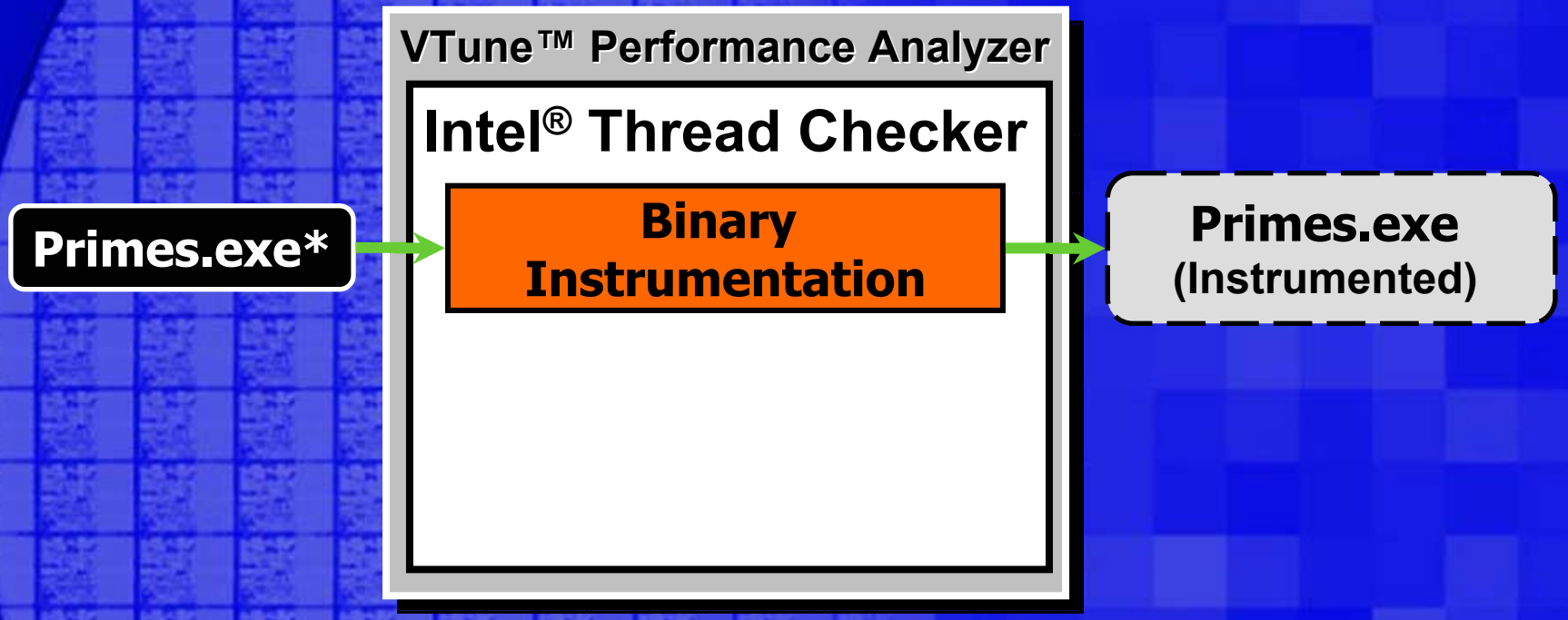
Intel® Thread Checker



*Compilation options: /Zi /O0
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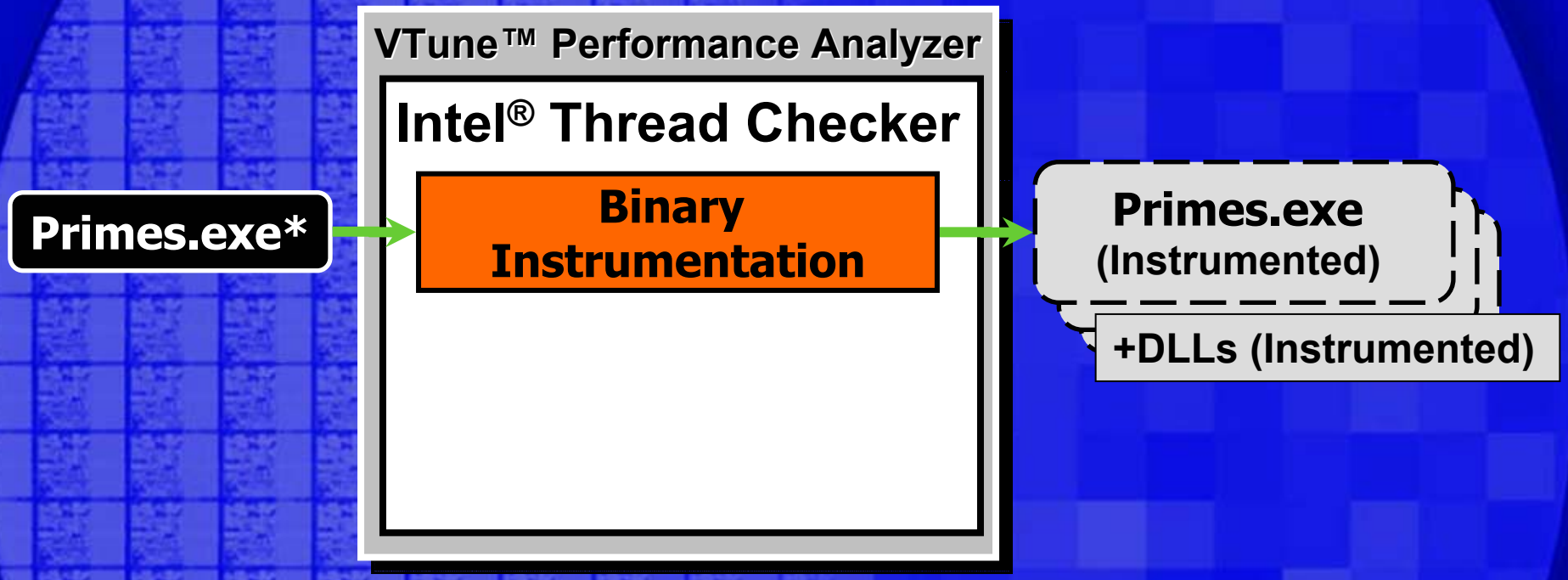
Intel® Thread Checker



*Compilation options: /Zi /O0
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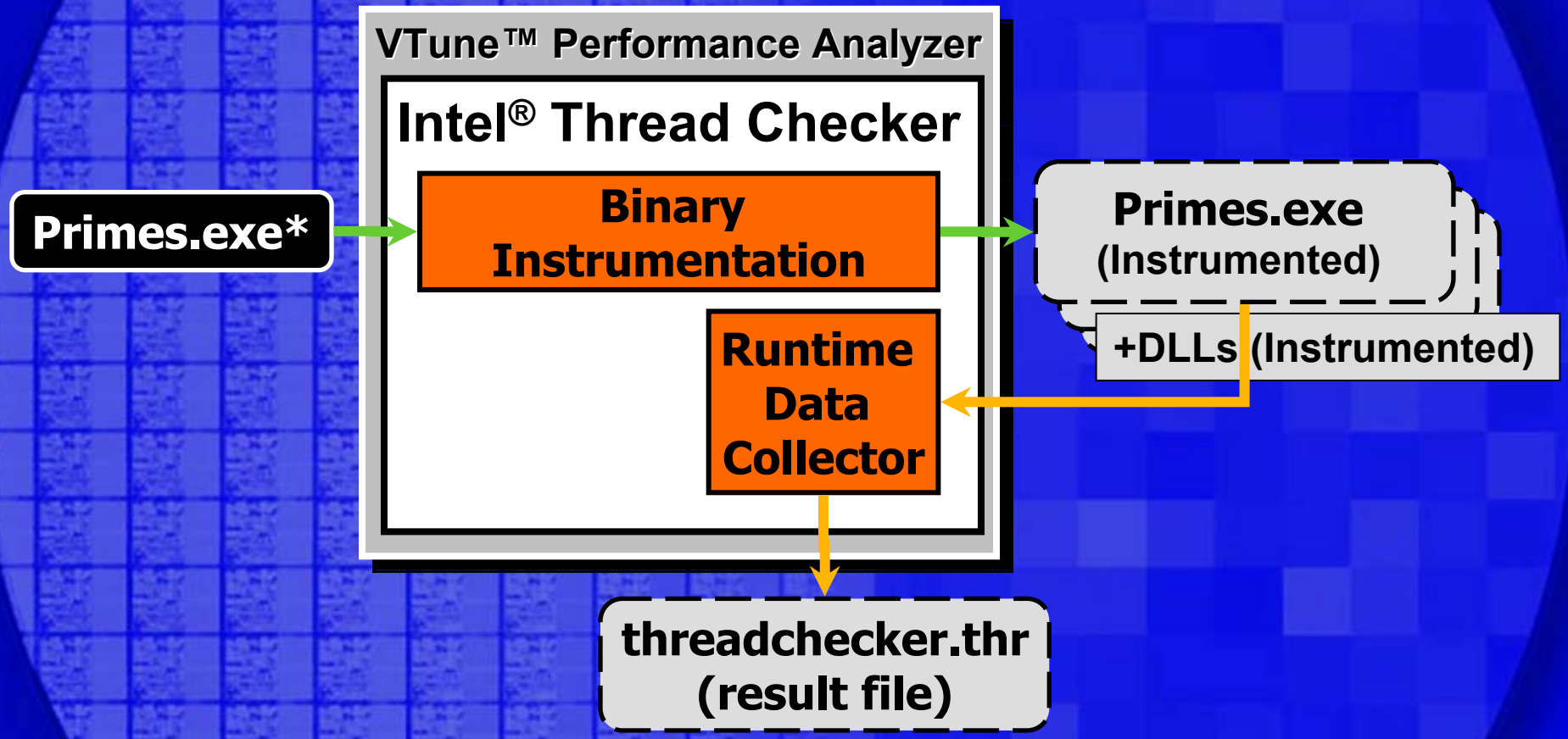
Intel® Thread Checker



*Compilation options: /Zi /O0
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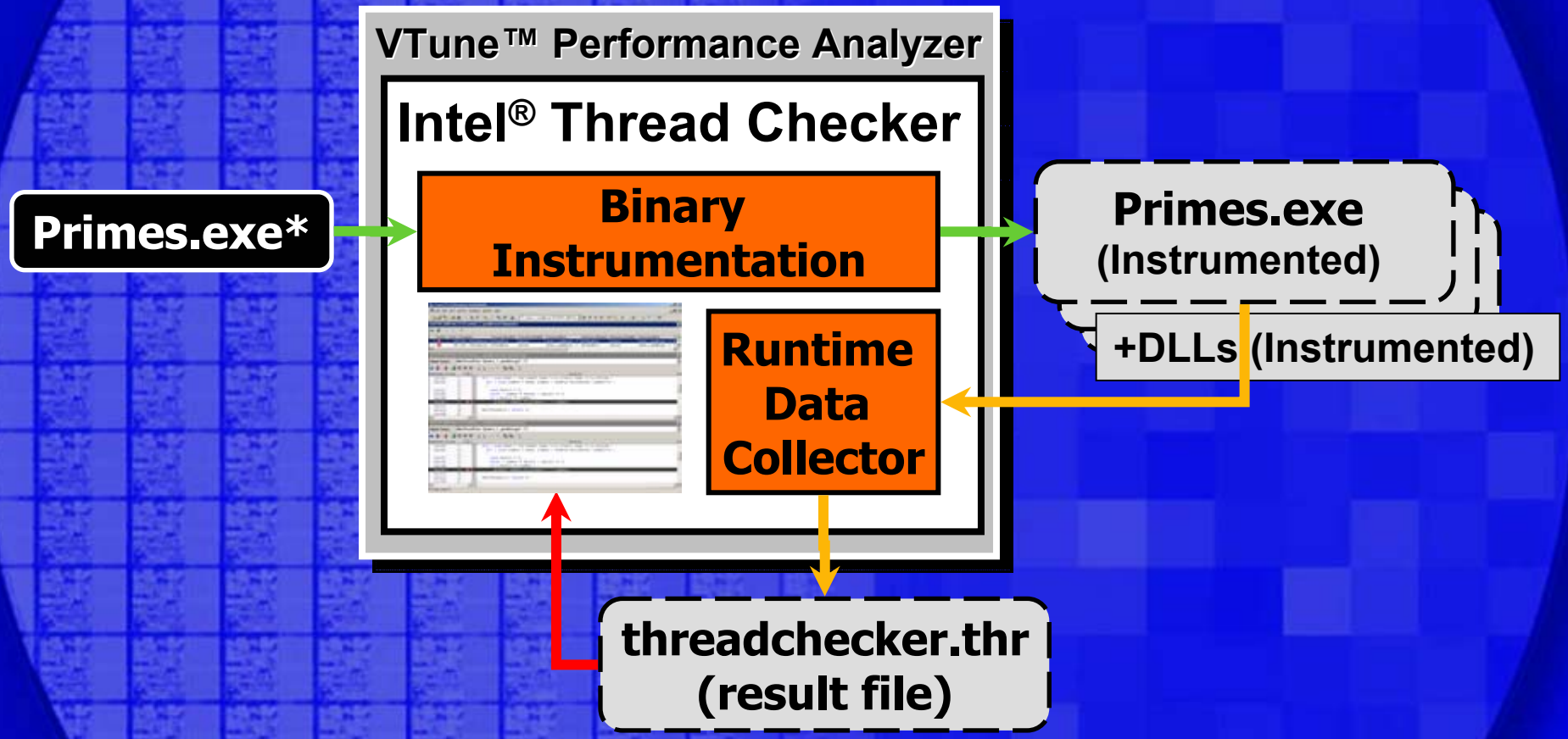
Intel® Thread Checker



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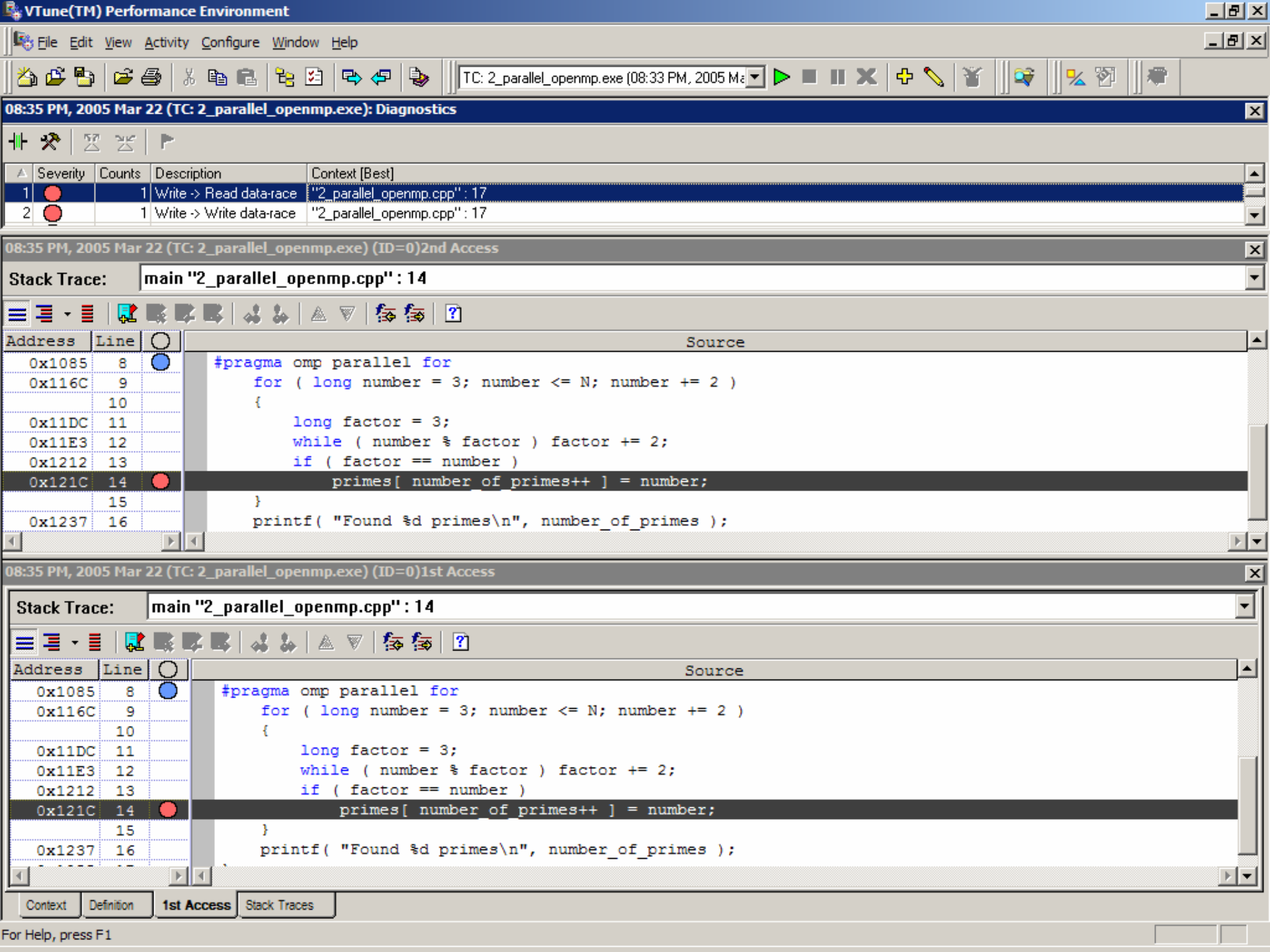
VTune(TM) Performance Environment
File Edit View Activity Configure Window Help
TC: 2_parallel_openmp.exe (08:33 PM, 2005 Ma
08:35 PM, 2005 Mar 22 (TC: 2_parallel_openmp.exe): Diagnostics
Severity Counts Description Context [Best]
1 1 Write -> Read data-race "2_parallel_openmp.cpp" : 17
2 1 Write -> Write data-race "2_parallel_openmp.cpp" : 17
08:35 PM, 2005 Mar 22 (TC: 2_parallel_openmp.exe) (ID=0)2nd Access
Stack Trace: main "2_parallel_openmp.cpp" : 14
Address Line Source
0x1085 8 #pragma omp parallel for
0x116C 9 for (long number = 3; number <= N; number += 2)
10 {
0x11DC 11 long factor = 3;
0x11E3 12 while (number % factor) factor += 2;
0x1212 13 if (factor == number)
0x121C 14 primes[number_of_primes++] = number;
15 }
0x1237 16 printf("Found %d primes\n", number_of_primes);
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Context Definition 1st Access Stack Traces
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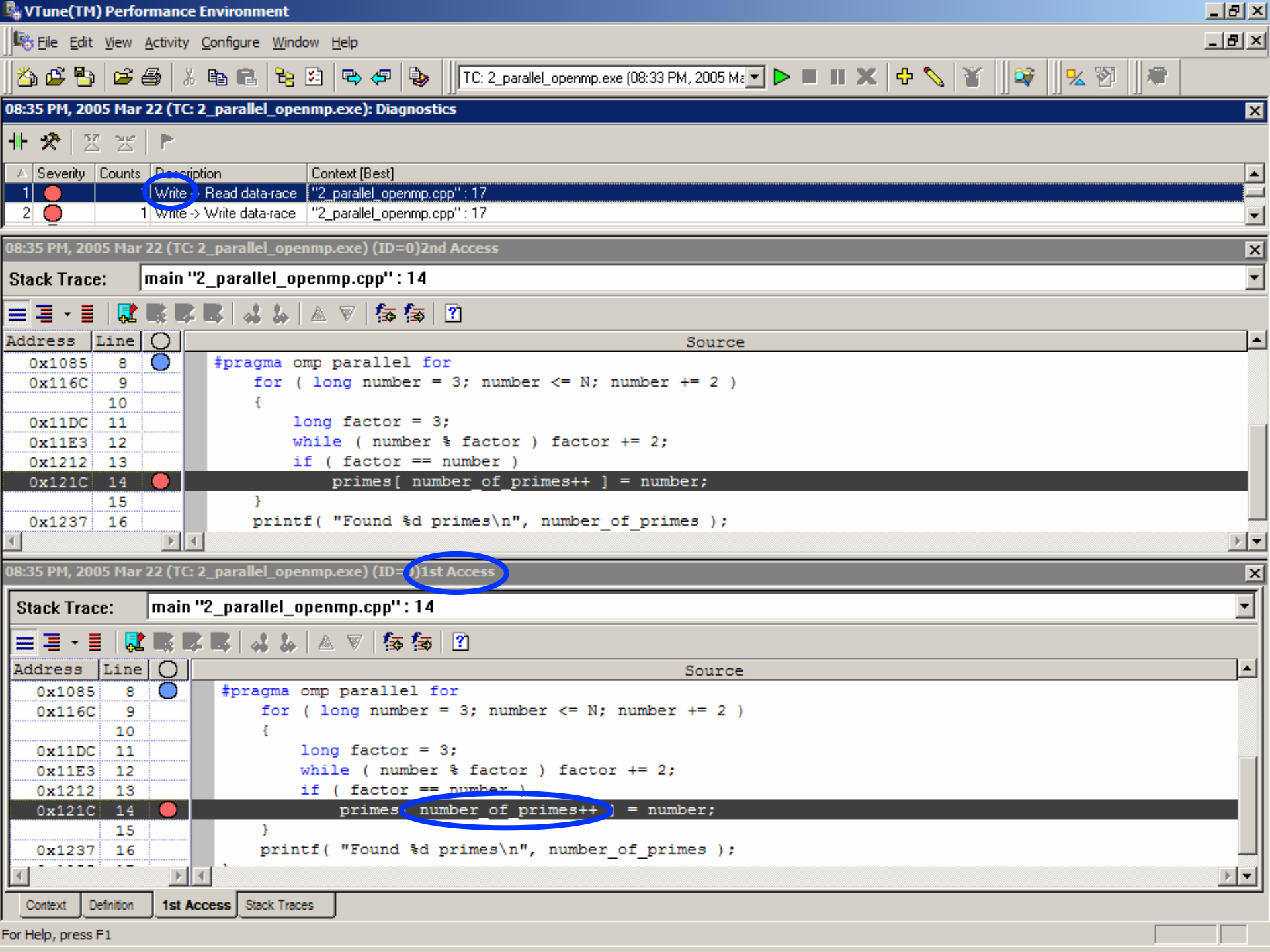
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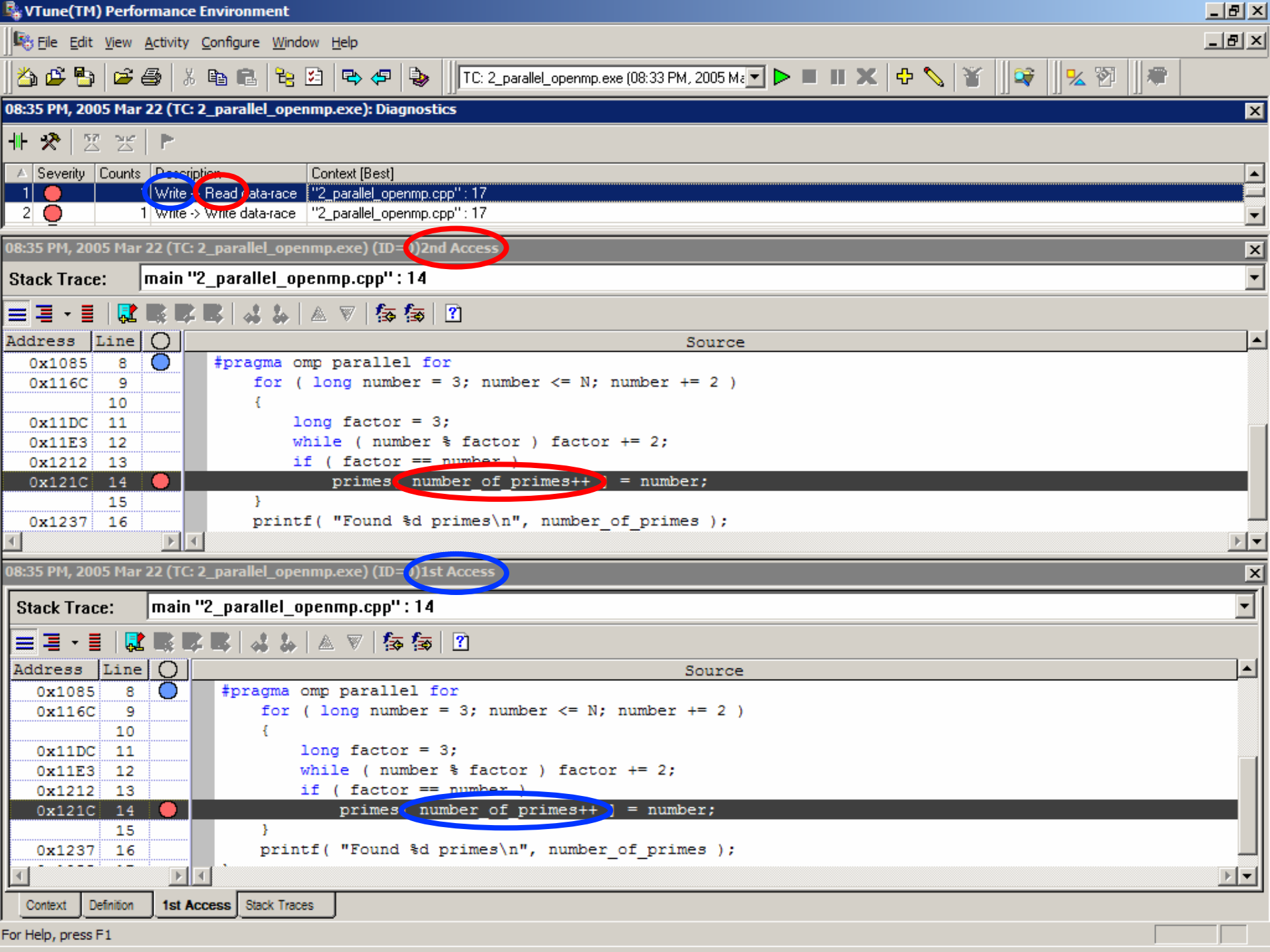
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Context Definition 1st Access Stack Traces
For Help, press F1

Example: Prime Number Generation

```
#include <stdio.h>
const long N = 100000;
long primes[N], number_of_primes = 0;
main()
{
  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case
#pragma omp parallel for
  for ( long number = 3; number <= N; number += 2 )
  {
    long factor = 3;
    while ( number % factor ) factor += 2;
    if ( factor == number )

      primes[ number_of_primes++ ] = number;
  }
  printf( "Found %d primes\n", number_of_primes );
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  for ( long number = 3; number <= N; number += 2 )
  {
    long factor = 3;
    while ( number % factor ) factor += 2;
    if ( factor == number )
#pragma omp critical
      primes[ number_of_primes++ ] = number;
  }
  printf( "Found %d primes\n", number_of_primes );
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Example: Prime Number Generation

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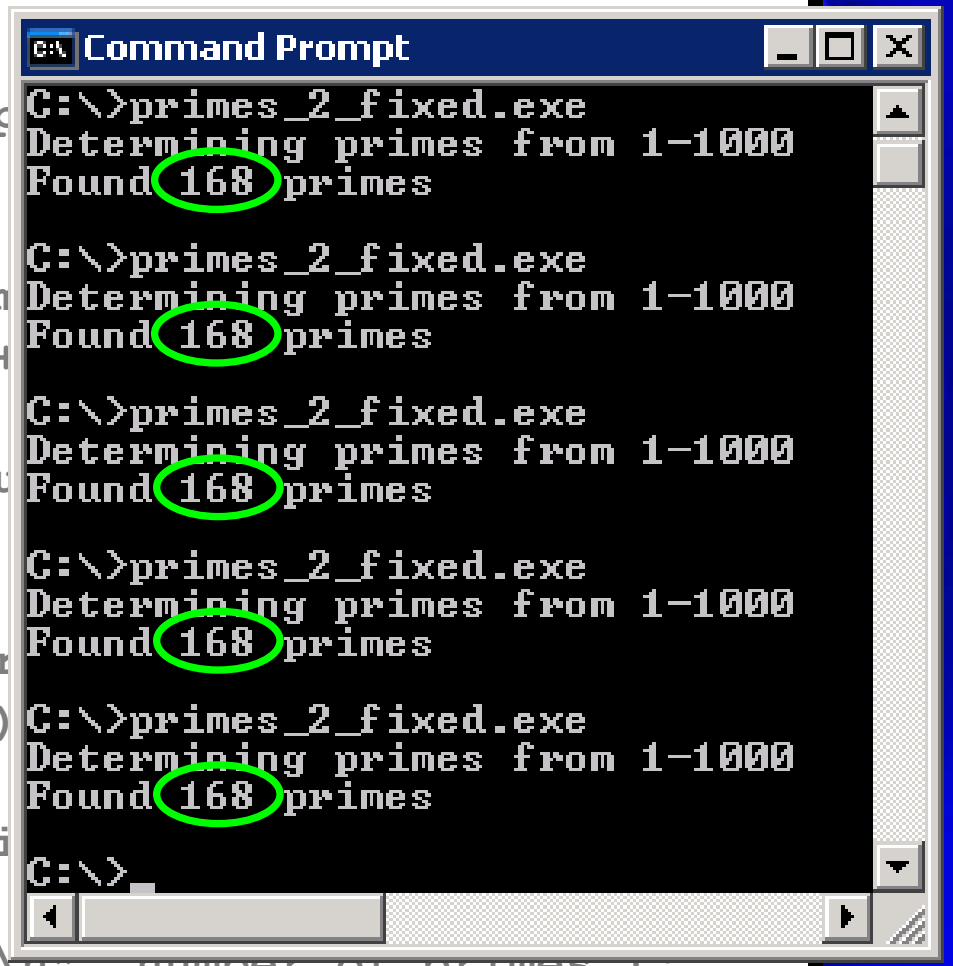
const long N = 100000;
long primes[N], number_of_p
main()
{
  printf( "Determining prim
  primes[ number_of_primes+
#pragma omp parallel for
  for ( long number = 3; nu
  {
    long factor = 3;
    while ( number % factor
    if ( factor == number )
#pragma omp critical
      primes[ number_of_pri
  }
  printf( "Found %d primes\n", number_of_primes );
}
```



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Identify synchronization objects that cause delays

OpenMP*, Win32* threads, POSIX* threads

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Example: Prime Number Generation

```
#include <windows.h>
#include <stdio.h>

const long N = 1000;
long primes[N], number_of_primes = 0;


typedef struct { long seed, limit, stride, blocksize; } THREAD_ARGS;
DWORD WINAPI MyThreadFunc( LPVOID pThreadArgs )
{
  THREAD_ARGS* p = (THREAD_ARGS*)pThreadArgs;
  for ( long base = 3+p->seed; base <= p->limit; base += p->stride )
    for ( long number = base; number < base+p->blocksize; number+=2 )
    {
      long factor = 3;
      while ( number % factor ) factor += 2;
      if ( factor == number )
        primes[ number_of_primes++ ] = number;
}
  ExitThread(0); return 0;
}

main()
{
  // Decompose computation across processors
  SYSTEM_INFO info; GetSystemInfo(&info);
  int num_threads = info.dwNumberOfProcessors;
  HANDLE* pThreadHandles = (HANDLE*)malloc( num_threads * sizeof(HANDLE) );
  THREAD_ARGS* pThreadArgs =
    (THREAD_ARGS*)malloc( num_threads * sizeof(THREAD_ARGS) );

  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case

  for ( int thread = 0; thread < num_threads; thread++ )
  {
    pThreadArgs[thread].blocksize = N / num_threads;
    pThreadArgs[thread].seed = thread * pThreadArgs[thread].blocksize;
    pThreadArgs[thread].limit = N;
    pThreadArgs[thread].stride =
                num_threads * pThreadArgs[thread].blocksize;

    pThreadHandles[thread] =
                CreateThread(0,0,MyThreadFunc,(LPVOID)(pThreadArgs+thread),0,0);
  }
  WaitForMultipleObjects( num_threads, pThreadHandles, TRUE, INFINITE );
  printf( "Found %d primes\n", number_of_primes );
}
```

Example: Prime Number Generation

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#include <windows.h>
#include <stdio.h>

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Example: Prime Number Generation

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    pThreadArgs[thread].limit = N;
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Example: Prime Number Generation

```
DWORD WINAPI MyThreadFunc( LPVOID pThreadArgs )
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  for ( long base = 3+p->seed; base <= p->limit; base += p->stride )
    for ( long number = base; number < base+p->blocksize; number+=2 )
    {
      long factor = 3;
      while ( number % factor ) factor += 2;
      if ( factor == number )
        primes[ number_of_primes++ ] = number;
  }
```

```
ma
{
  ..
  fo
  {
    pThreadArgs[thread].limit = N;
    pThreadArgs[thread].stride = num_threads * pThreadArgs[thread].blocksize;

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```

```
  printf( "Found %d primes\n", number_of_primes );
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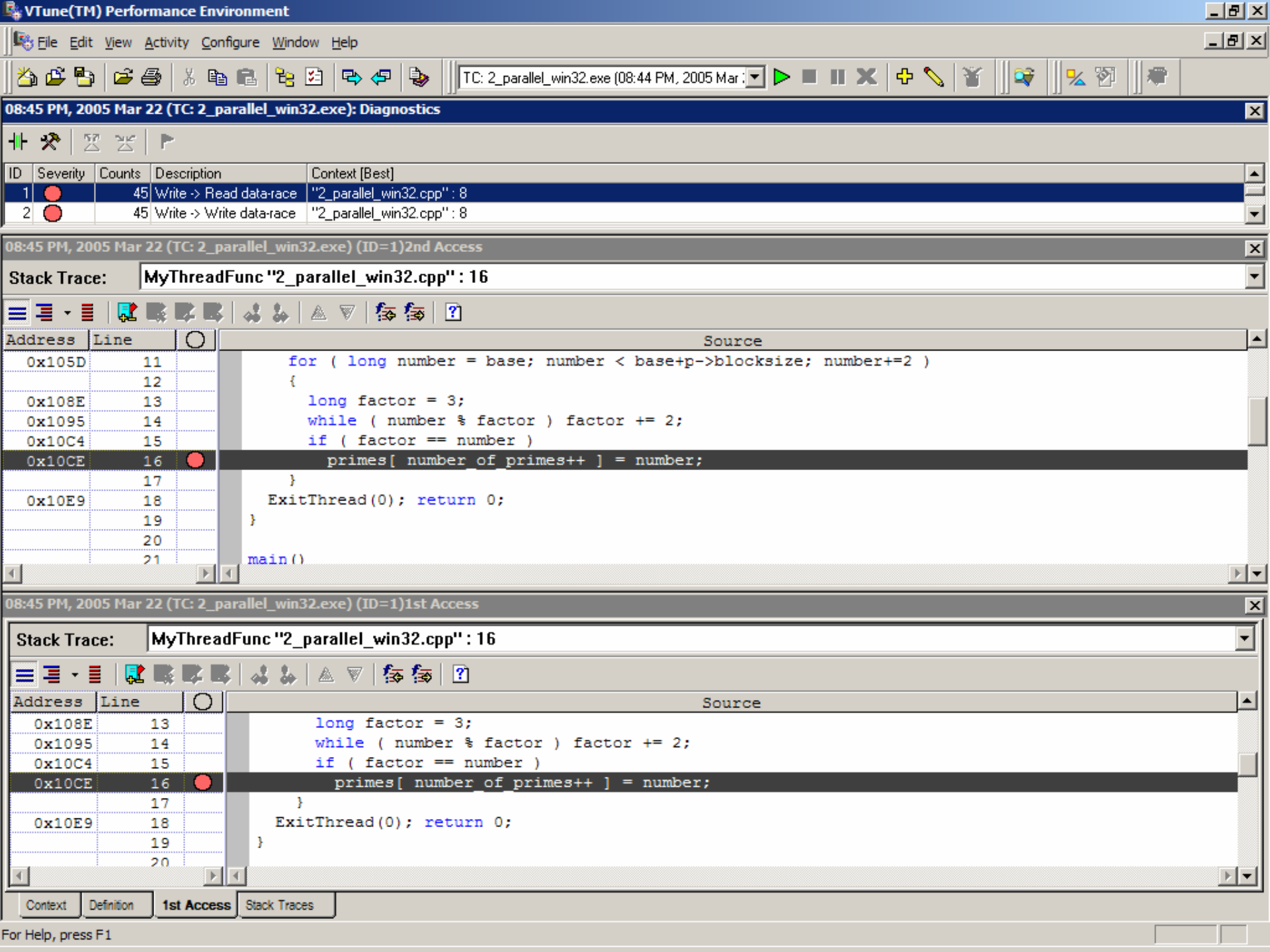
VTune(TM) Performance Environment
File Edit View Activity Configure Window Help
TC: 2_parallel_win32.exe (08:44 PM, 2005 Mar
08:45 PM, 2005 Mar 22 (TC: 2_parallel_win32.exe): Diagnostics
ID Severity Counts Description Context [Best]
1 45 Write -> Read data-race "2_parallel_win32.cpp" : 8
2 45 Write -> Write data-race "2_parallel_win32.cpp" : 8
08:45 PM, 2005 Mar 22 (TC: 2_parallel_win32.exe) (ID=1)2nd Access
Stack Trace: MyThreadFunc "2_parallel_win32.cpp" : 16
Address Line Source
0x105D 11 for (long number = base; number < base+p->blocksize; number+=2)
12 {
0x108E 13 long factor = 3;
0x1095 14 while (number % factor) factor += 2;
0x10C4 15 if (factor == number)
0x10CE 16 primes[number_of_primes++] = number;
17 }
0x10E9 18 ExitThread(0); return 0;
19 }
20
21 main()
08:45 PM, 2005 Mar 22 (TC: 2_parallel_win32.exe) (ID=1)1st Access
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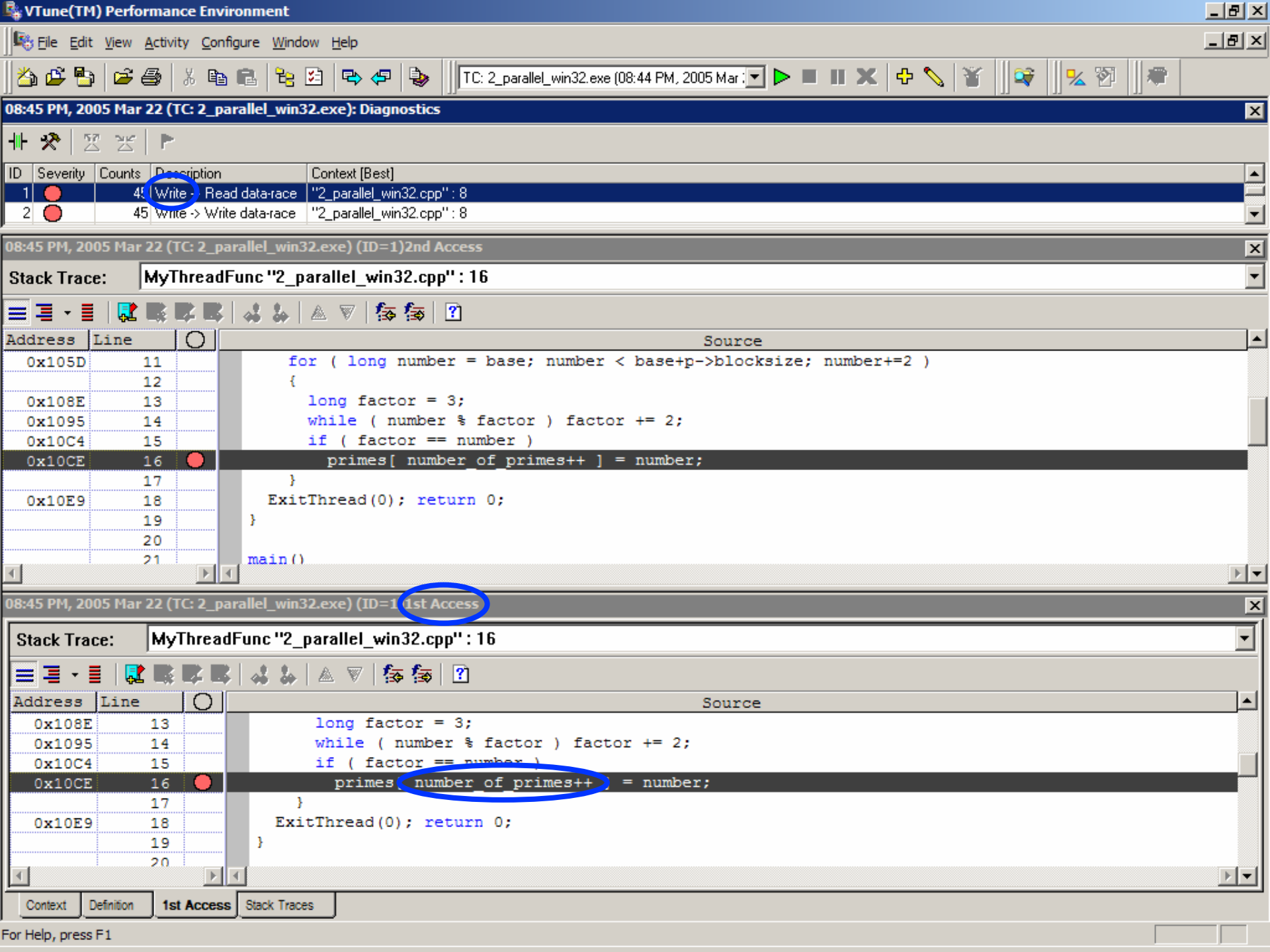
Context Definition 1st Access Stack Traces
For Help, press F1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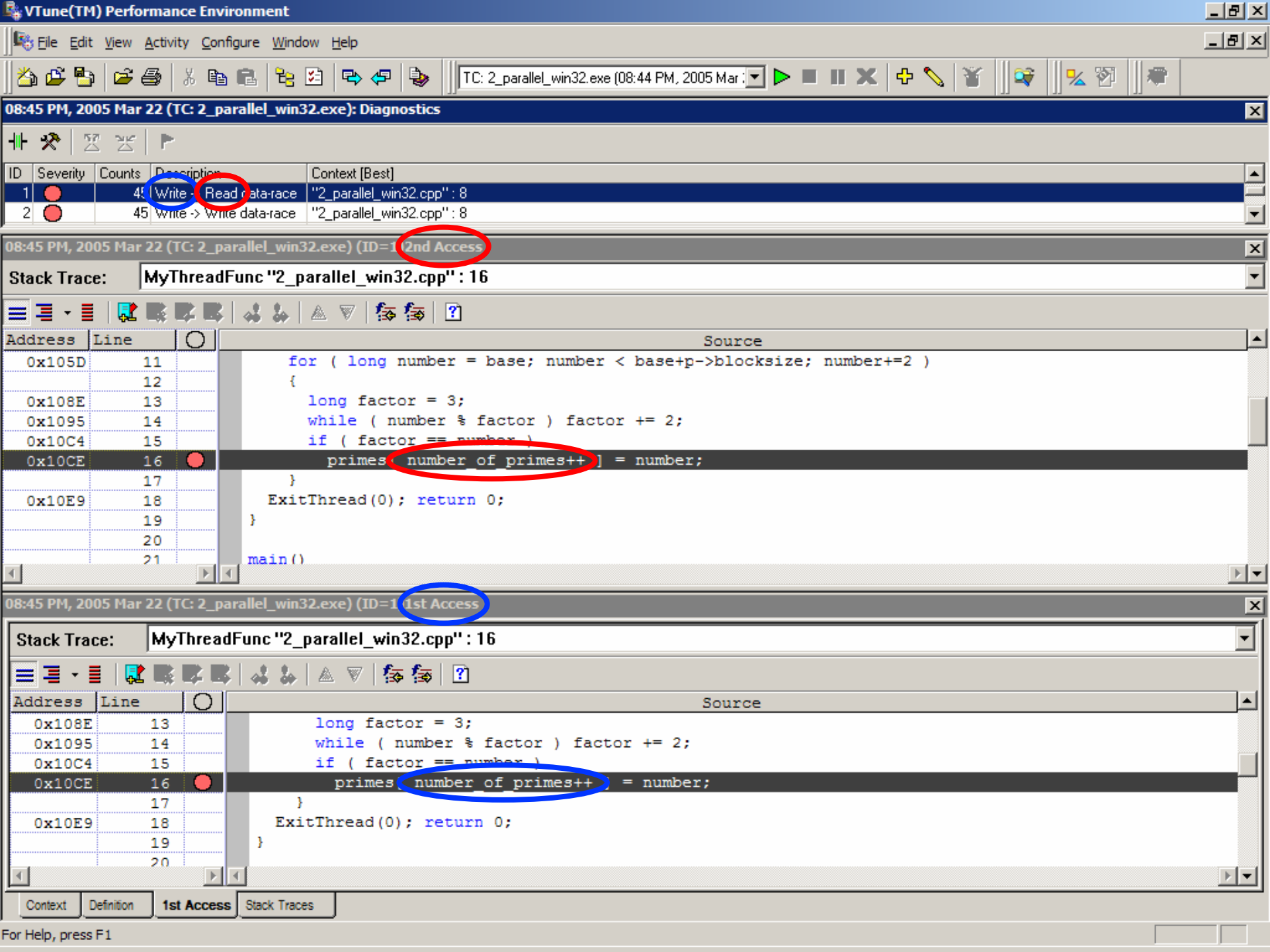
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Example: Prime Number Generation

```
#include <windows.h>
#include <stdio.h>

const long N = 1000;
long primes[N], number_of_primes = 0;
CRITICAL_SECTION primes_cs;

typedef struct { long seed, limit, stride, blocksize; } THREAD_ARGS;
```

```
#include <windows.h>
#include <stdio.h>

const long N = 1000;
long primes[N], number_of_primes = 0;
CRITICAL_SECTION primes_cs;

typedef struct { long seed, limit, stride, blocksize; } THREAD_ARGS;
DWORD WINAPI MyThreadFunc( LPVOID pThreadArgs )
{
```

```
  printf( "Determining primes from 1-%d \n", N );
  primes[ number_of_primes++ ] = 2; // special case
  InitializeCriticalSection( &primes_cs );
  for ( int thread = 0; thread < num_threads; thread++ )
  {
    pThreadArgs[thread].blocksize = N / num_threads;
    pThreadArgs[thread].seed = thread * pThreadArgs[thread].blocksize;
    pThreadArgs[thread].limit = N;
    pThreadArgs[thread].stride =
                num_threads * pThreadArgs[thread].blocksize;

    pThreadHandles[thread] =
                CreateThread(0,0,MyThreadFunc,(LPVOID)(pThreadArgs+thread),0,0);
  }
  WaitForMultipleObjects( num_threads, pThreadHandles, TRUE, INFINITE );
  printf( "Found %d primes\n", number_of_primes );
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const long N = 1000;
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typedef struct { long seed, limit, stride, blocksize; } THREAD_ARGS;
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main()
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  // Decompose computation across processors
  SYSTEM_INFO info; GetSystemInfo(&info);
  int num_threads = info.dwNumberOfProcessors;
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DWORD WINAPI MyThreadFunc( LPVOID pThreadArgs )
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  THREAD_ARGS* p = (THREAD_ARGS*)pThreadArgs;
  for ( long base = 3+p->seed; base <= p->limit; base += p->stride )
    for ( long number = base; number < base+p->blocksize; number+=2 )
    {
      long factor = 3;
      while ( number % factor ) factor += 2;
      if ( factor == number )
      {
        EnterCriticalSection( &primes_cs );
        primes[ number_of_primes++ ] = number;
        LeaveCriticalSection( &primes_cs );
      }
    }
```

```
InitializeCriticalSection( &primes_cs );
for ( int thread = 0; thread < num_threads; thread++ )
{
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```
  }
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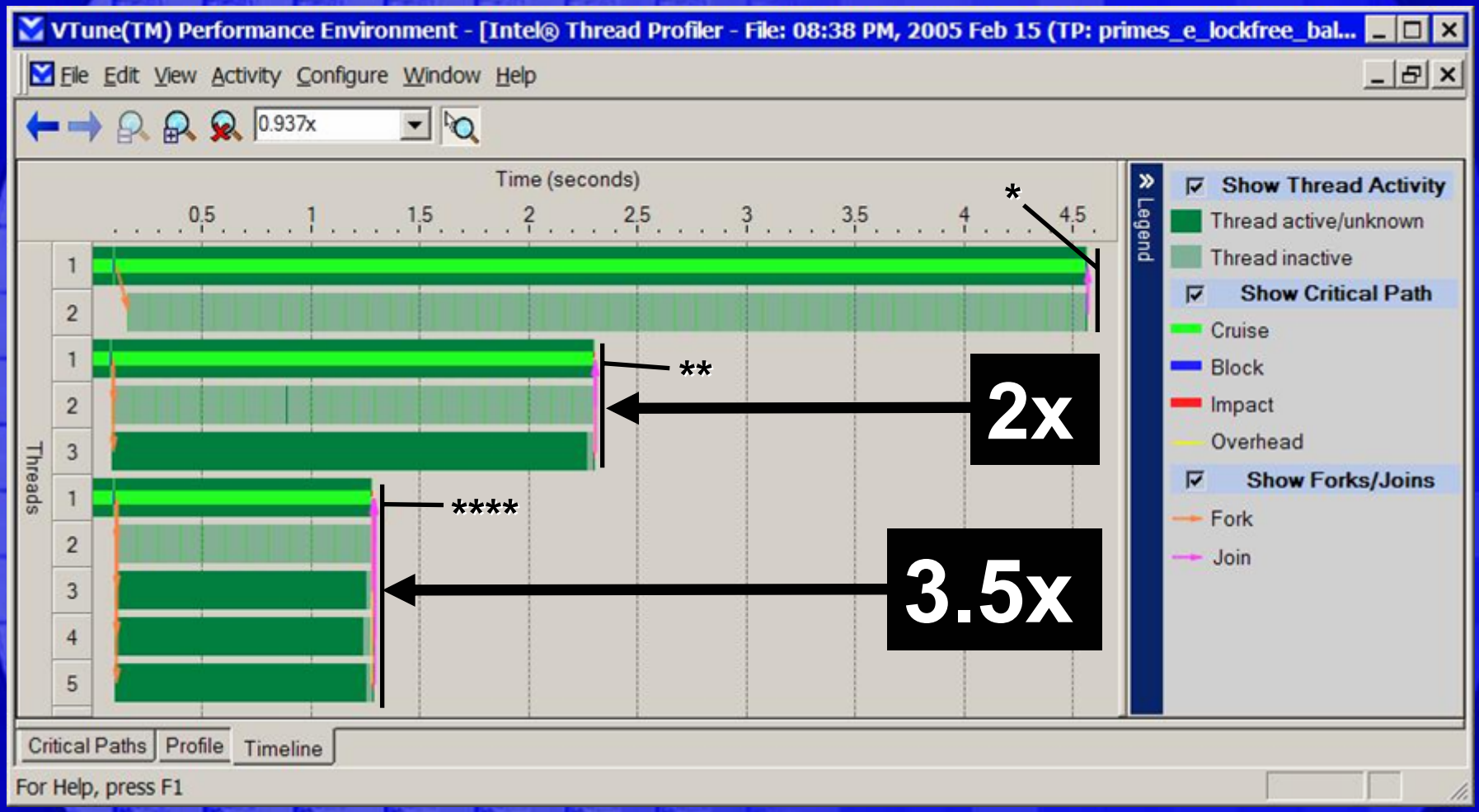
Intel® Thread Profiler



* Intel® Xeon™ (HT Technology DISABLED)
** Dual-processor Intel® Xeon™ (HT Technology DISABLED)
**** Dual-processor Intel® Xeon™ (HT Technology ENABLED)

Summary

- Decompose processing across parallel compute threads
- OS schedules active threads to execute on logical processors
- Multiple execution cores ramping across Intel platforms

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Create threaded apps. more quickly with OpenMP* and the Intel® Threading Tools: www.intel.com/software/products

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Additional Resources

Thread Profiler for Win32* Threads

https://shale.intel.com/SoftwareCollege/CourseDetails.asp?courseID=220

Developing Multithreaded Applications: A Platform Consistent Approach

Search intel.com for “AppDevelopment.pdf”

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Supported Platforms

Windows*

- Microsoft Windows* XP Professional
- Microsoft Windows* 2000
- Microsoft Windows* Server 2003

Linux* (Remote Agent)

- Red Hat* Application Server 2.1**
- Red Hat* Enterprise Linux* 3.0
- Red Hat* Enterprise Linux* 4.0
- Red Flag* 4.1
- SUSE LINUX Enterprise Server* 9.0

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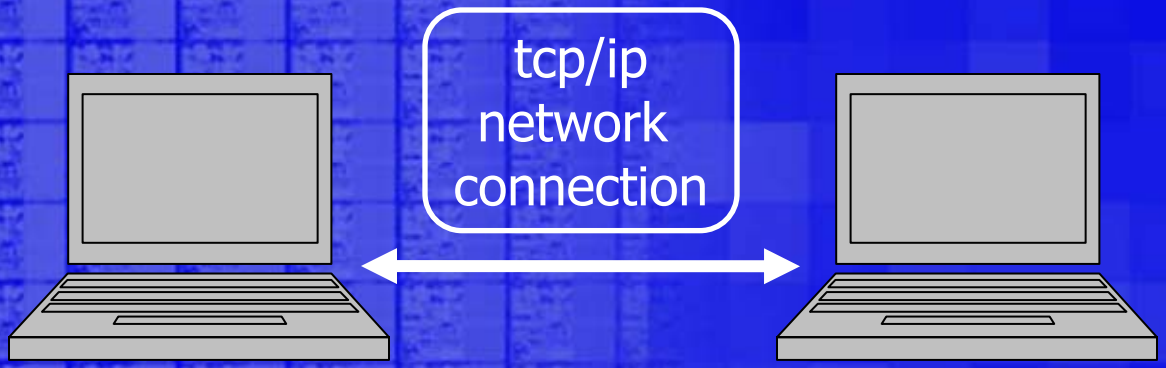
** Pentium®-based systems only

Remote Analysis on Linux*



Windows* System
Intel® Thread Profiler

Linux* System
Intel Thread Profiler
Remote Agent for Linux*

Configure Activity → **Analyze** → **View Results**

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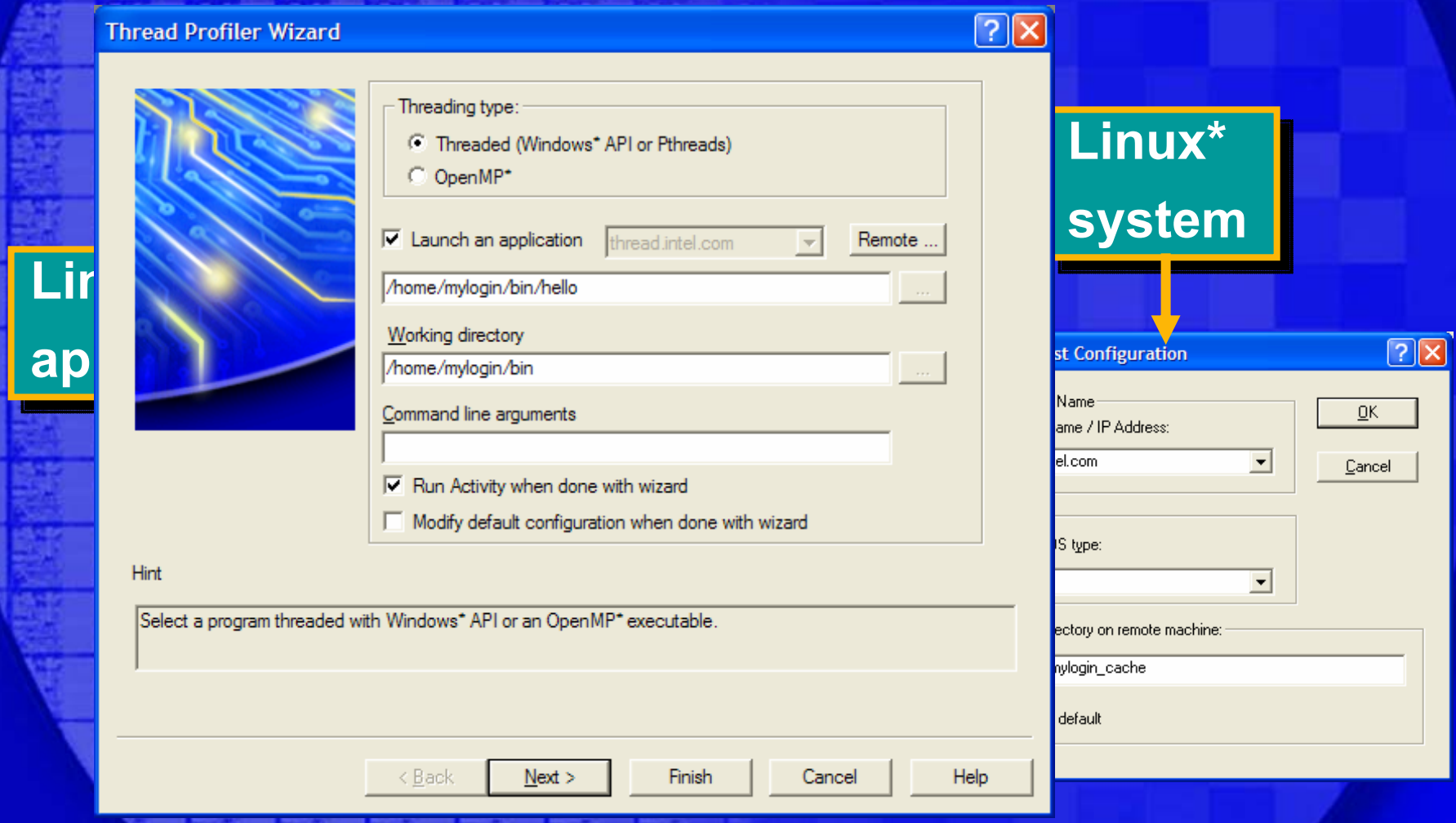
Remote Analysis on Linux*



User Synchronization Support

ITT User Sync API

```
void __itt_notify_sync_prepare( void* pSyncVar );
void __itt_notify_sync_cancel( void* pSyncVar );
void __itt_notify_sync_acquired( void* pSyncVar );
void __itt_notify_sync_releasing( void* pSyncVar );
```

(Include libittnotify.h, Link with libittnotify.lib)

Usage Example

```
volatile long myLock = 0;
__itt_notify_sync_prepare( &myLock );
while( !InterlockedCompareExchange(&myLock, 1, 0) );
__itt_notify_sync_acquired( &myLock );

// <atomic section>

__itt_notify_sync_releasing( &myLock );
InterlockedDecrement( &myLock );
```